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Trends in Gestational Weight Gain in South Carolina, 2004 - 2015

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Abstract

Objective: Excessive and inadequate gestational weight gain (GWG) are associated with a myriad of adverse pregnancy outcomes. The objective of this study was to examine secular trends in GWG in South Carolina (SC) from 2004 to 2015. We hypothesized that there was a trend of higher GWG z scores (GWGZ) over this 11-year time period after adjusting for changes in population characteristics. We also hypothesize that a trend of higher mean GWGZ at higher percentiles is more apparent for African Americans, rural women, and women who are overweight or obese before pregnancy.

Data and Methods: Data came from SC 2004-2015 birth certificates (n = 525,411). In this study, we used gestational-age-standardized GWGZ, which were calculated using smoothed reference values for GWG to account for gestational age and pre-pregnancy BMI. Quantile regression models were used to understand GWGZ trends over time at different percentiles of GWGZ, adjusting for important maternal characteristics. We further evaluated the modifying effects of maternal race, maternal pregnancy BMI and rural/urban residence on the GWG trends.

Results: SC women had an overall mean GWGZ of -0.40. We saw an overall increase in GWGZ in the 5th and 10th percentiles and an overall decrease in the 25th, 50th, 75th, 90th, and 95th percentiles (2004-2015). White women had a higher increase in GWGZ in the 5th percentile compared to African American women. In the 95th percentile, White women had a higher

decrease in GWGZ compared to African American women. Rural residents had significantly lower GWGZ in the 5th percentile and modest increases in GWGZ compared to urban residents. Lastly, underweight women showed decreases in the 5th percentile of GWGZ and overweight and obese women showed negligible changes in GWGZ in the 90th and 95th percentiles.

Implication and significance: Knowledge about the trends of GWG in SC women and its correlates is helpful for addressing health concerns of high risk populations, such as racial minority groups and women who are underweight or overweight before pregnancy. GWGZ scores as a GWG measure and quantile regression models are feasible for trend analyses of GWG.

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Chapter 1

Introduction and Background

1.1 Increasing Trend in Obesity in the United States

Obesity, a major health concern in the United States, has increased over the past decades (Fisher, et al., 2013; Flegal et al., 2016). Obesity rates are higher in women compared to men (Flegal et al., 2010, 2016). A recent study found that the prevalence of obesity among women (ages 20 to 60) was 40.5% in 2013-2014 and the odds of being obese in 2013-2014 was 23% higher compared to 2005-2006 (Flegal et al., 2016). Obesity has serious health consequences such as increased risks for all-cause mortality, high blood pressure (or hypertension), type 2 diabetes, and coronary heart disease (Alberico et al., 2014; Bhaskaran et al., 2014; NHLBI Obesity Education Initiative Expert Panel on the Identification, Evaluation, and Treatment of Obesity in Adult*s*, 1998; Morisset et al, 2017). In addition, women who are overweight or obese entering pregnancy are more likely to have excessive gestational weight gain (Morisset, et al, 2017, Rasmussen & Yaktine, 2009).

1.2 Gestational Weight Gain

Gestational weight gain (GWG), defined as the difference of pregnant women's weight at delivery and her pre-pregnancy weight, has received increasing attention in the backdrop of this obesity epidemic. The 1990 Institute of Medicine (IOM) recommendations for GWG gave guidelines according to pre-pregnancy BMI, which postulated that all women should gain at least 15 pounds during pregnancy to protect against inadequate GWG (Luke, 1991; Rasmussen, et al., 2009). Due to an increasing prevalence of excessive GWG, in 2009, IOM revised these guidelines by using WHO's BMI cut-off points and setting an upper limit for weight gain for obese women (Rasmussen & Yaktine, 2009). This revision was administered with the intention of creating updated guidelines that improve health outcomes in reproductive aged women and their offspring (Rasmussen & Yaktine, 2009). These revised guidelines are more effective in addressing the issue of gaining excessive weight during pregnancy, which is crucial due to the increasing prevalence of obesity among reproductive aged women. Table 1 displays the GWG recommendations according to the 1990 and 2009 IOM guidelines.

Table 1.1 Institute of Medicine recommendations for gestational weight gain (1990, 2009)

	Total weight gain (lbs)		Rate of weight gain in 2nd and 3rd trimester (lb/week)	
Pre-pregnancy BMI	**1990[1]**	**2009[2]**	**1990[1]**	**2009[2]**
Underweight	28 - 40	28 - 40	~1	1
Normal weight	25 - 35	25 – 35	1	1
Overweight	15 - 25	15 - 25	.66	.6
Obese	≥ 15	11 - 20	Not specified	.5

[1]Institute of Medicine, 2009 [2]Rasmussen & Yaktine, 2009

Gaining an inadequate or excessive amount of weight during pregnancy has important health risks for the mother and child (Deputy, Sharma, Kim, & Hinkle, 2015).

Women who gain an excessive or inadequate weight during pregnancy are at increased risk for large for gestational age or small for gestational age offspring, respectively (Gavard, 2017). For mothers, excessive GWG has been related to increased risk of obesity after the pregnancy, gestational diabetes, type 2 diabetes, cardiovascular disease, and metabolic syndrome, as well as increased risk for macrosomia in the offspring (Alberico et al., 2014; Chen et al., 2015; Gilmore et al., 2015; Guo et al., 2015; Tian et al., 2016; Zamorski & Biggs, 2001). For children, excessive GWG also contributes to the obesity epidemic because macrosomic newborns are more likely to become obese during childhood (Hinkle et al., 2012; Margerison-Zilko et al., 2012; Santangeli et al., 2015; Xie, Wang, Li, & Wen, 2016). Inadequate GWG is associated with low birth weight offspring, which is related to higher risk of morbidity and mortality (Iliodromiti et al., 2017). Improper weight gain during pregnancy has clear health consequences for the mothers and offspring and may have contributed to the increasing prevalence of overweight and obese in women themselves as well as their offspring.

Despite these clear health consequences associated with inappropriate GWG, the prevalence of gaining excessive or inadequate weight during pregnancy is relatively common and the prevalence of excessive GWG may be on an upward trend. In the United States during the period of 2012 and 2013, only one third of women met IOM's recommendations for GWG, 20% gained inadequate weight during pregnancy, while approximately 50% gained excessive weight during pregnancy (Deputy et al., 2015). In 17 out of 46 states that were studied, the prevalence of excessive GWG was greater than 50%, demonstrating the severity of this health issue for reproductive aged women in the US (Deputy et al., 2015). The goal of the current IOM recommendations for GWG is to improve health outcomes for mothers and children, so it is concerning that there is such a large proportion of women who are not able to gain the appropriate amount of gestational weight.

1.3 Determinants of Gestational Weight Gain

Understanding the individual characteristics that put a woman at increased risk for inappropriate GWG is crucial. Factors that are commonly related to GWG include parity, rural/urban residence, race/ethnicity, maternal pre-pregnancy BMI, socioeconomic status and smoking behavior (Deputy et al., 2015; Gallagher et al., 2013; Headen et al., 2012; Headen et al., 2015; Klingberg et al., 2017; Rasmussen & Yaktine, 2009). Parity, a measure of the number of previous pregnancies a woman has experienced, is related to GWG and cardiovascular events for the mother (Klingberg et al., 2017). Women who are in high parity are more likely to be overweight or obese prior to pregnancy and are more likely to experience negative health outcomes such as cardiovascular disease (Klingberg et al., 2017). Urban or rural residence impacts weight gain since rural areas have higher proportions of low income and racial minority groups (Gallagher et al., 2013). Despite this fact, women in rural settings are less likely to gain excessive weight during pregnancy if they are overweight or obese prior to pregnancy (Gallagher et al., 2013). Although rural areas may contain high risk populations, living in this setting is protective against excessive GWG since we see that rural residents gain less weight during pregnancy than urban residents (Gallagher et al., 2013). Pre-pregnancy BMI is an important predictor of GWG, since overweight and obese women are more likely to gain excessive weight during pregnancy and underweight women are more likely to gain inadequate weight during pregnancy (Pongcharoen et al., 2016; Rasmussen & Yaktine, 2009; Tabatabaei, 2011). Socioeconomic status (SES) is related to GWG as those who are considered low SES are more likely to have excessive GWG (Clayborne et al., 2017; Huynh et al., 2014). WIC participation can be used as a proxy for SES, since those who qualify for WIC tend to be lower SES and are considered vulnerable (Figlio et al., 2009; Kotelchuck et al., 1984; Lee & Mackey-Bilaver, 2007). Smoking behaviors among reproductive aged women are important to study while examining trends in GWG, since women who smoke during pregnancy tend to gain less weight and have higher risk for low birth weight in offspring (Rode et al., 2013). In recent years, the prevalence of smoking among women has decreased from 18.1% in 2005 to 14.8% in 2014 so including this variable in our study is important to understand if increased smoking cessation or overall decreased smoking prevalence impacts GWG (Jamal et al., 2015). Age is also a factor that influences GWG, since older women are more likely to be overweight and obese (Mathews & Hamilton, 2014; Flegal et al., 2016). As the pregnant population become older, they are more likely to gain excessive weight during pregnancy due to their increased pre-pregnancy BMI. Identifying important characteristics like these helps us to better understand which high risk groups are most likely to have inappropriate GWG and are therefor at risk for subsequent health problems.

Prior studies have found that GWG varies by race/ethnicity and women's pre-pregnancy weight status. Gaining excessive weight during pregnancy is more prevalent in white women than African American women, although both racial groups experience a high prevalence of excessive GWG (Deputy et al., 2015; Headen et al., 2012; Headen et al., 2015; Liu et al., 2014; Rasmussen & Yaktine, 2009). White women experience increased risk for excessive GWG if they are either overweight or obese before pregnancy and African American and Hispanic women experienced increased risk for inadequate GWG if they are normal weight or underweight before pregnancy (Fontaine et al., 2012; Headen et al., 2015). Although the risk for GWG is higher among white women, approximately 45% of African American women ages 20 to 39 are obese (Flegal et al., 2016) and over 40% experience excessive GWG (Headen et al., 2012). African American women that were 20 years or older had significantly increased odds of obesity from 1999 to 2010, compared to white women (Ogden et al., 2012). African American and Hispanic populations also have high proportions of individuals with low SES, which may partly explain the high prevalence of obesity in these women (Liu et al., 2014). Due to the fact that racial minority groups are at a higher risk for excessive or inadequate GWG, it is important to examine recent trends by race/ethnicity and GWG. Findings in this area will be important for identifying high risk populations for future policy and program development which will ultimately help to reduce racial disparities in health outcomes.

1.4 Gestational weight gain in South Carolina

South Carolina (SC) population ranks the 13th highest for obesity rate in the nation, with an obesity rate of 31.7% (Levi et al., 2015). Among SC pregnant women in 2014, approximately 25% were overweight and 29% were obese before pregnancy (Branum et al., 2016). Only 22.8% of SC women gained weight within the 2009 IOM recommendations from 2004 to 2006: 48.8% had excessive GWG and 28.4% had inadequate GWG (Liu et al, 2014). SC has a large population of African American women, making up 28% of the state's population ("United States QuickFacts," 2016). Approximately 26% of these African American women are classified as overweight and 30% are classified as obese prior to pregnancy (Fisher et al., 2013). This racial group shows the highest prevalence of overweight or obesity compared to other racial categories, which may put African American women at an increased risk for exceeding IOM's GWG guidelines in this state. Similar to previous research, African American women in SC have lower levels of excessive GWG (45%) compared to Caucasian women (52.6%), but both racial groups have markedly high rates (Liu et al., 2014). Additionally, among African American and Hispanic women with pre-pregnancy BMI less than 25 kg/m^2, the odds of inadequate GWG was approximately 50% higher than that for Caucasian women (Liu et al., 2014).

Approximately 23% of the SC population lives in rural areas, which is important when studying GWG since rural residence may has been associated with GWG (Cromartie, 2016). A recent study found that women living in a rural SC had higher odds of being overweight or obese compared to urban women and there is a high proportion of racial minority groups living in rural areas (Gallagher et al., 2013; "South Carolina Rural Health Report" n.d.). Place of residence is related to GWG and that relationship is modified by BMI category prior to pregnancy (Gallagher et al., 2013). Compared to the urban setting, women living in a rural setting that were normal weight had increased odds of inadequate GWG, overweight women had decreased odds of excessive GWG and obese women had decreased odds of inadequate and excessive GWG (Gallagher et al., 2013). Rural setting was protective against unhealthy weight gain during pregnancy despite the increased proportion of obese and overweight status before pregnancy.

However, no study has ever examined whether the trend of GWG would vary by urban and rural residence.

An understanding of how trends in GWG have changed in the past decade in SC and how those trends vary by sub-populations is crucial for the design of intervention programs for pregnant women in SC. The current study explores recent trends in GWG to better understand if there are changes over time that are not demonstrated in current GWG trend research. This study focuses on factors associated with health disparities to better understand if there are high-risk populations that can be targeted with possible GWG interventions in the future. To overcome bias in GWG measurement used in previous studies, this study uses GWG z scores (GWGZ) (Hutcheon et al., 2012, 2015), which takes into account of varying gestational age at delivery. Quantile regression models will be used to examine the trends in GWGZ from 2004 until 2015 in SC. This robust method is appropriate for studying GWG, since there are high levels of women gaining excessive and inadequate weight during their pregnancy and that may result in skewed data. Application of these new methods uncovers interesting trends in GWG and by sub-groups. The findings can be used these to inform further programs and research.

1.5 Study Objectives, Aims and Hypotheses

The overarching objective of this study is to examine trends in GWG during the period of 2004-2015 and to determine whether some sub-groups have an increasing trend. Specifically, this will be answered via two study aims.

Study Aim #1: To examine the 11-year trends in GWG in South Carolina from 2004 to 2015. We will use gestational-age-standardized GWGZ with smoothed reference values for GWG that was drawn from a cohort of women from the Magee Women's Hospital in Pittsburgh, PA from 1998 to 2010 understand if there is an increasing trend in GWG (Hutcheon et al., 2012, 2015). Quantile regression models are used to better depict changes in GWG in high and low GWGZ percentiles over time.

Hypothesis 1: We hypothesize that overall GWGZ has increased in South Carolina over the past 11 years and increasing trends would be observed in all GWGZ percentiles, after adjusting for changes in other covariates such as pre-pregnancy BMI, race/ethnicity, parity, WIC participation, smoking behavior, residence, age and birth cohort.

<u>Study Aim #2</u>: To examine whether the 11-year trends in GWG in South Carolina vary according to rural/urban residence, race and maternal pregnancy BMI.

Hypothesis 2: We hypothesize that the trends in GWG z scores increased faster among overweight/obese women (compared to normal weight women), in African American women (vs. white women), in parous women (compared to nulliparous women), and in urban women (compared to rural women).

Chapter 2

Literature Review

2.1 Search methods

A systematic review of the current literature related to GWG trends was conducted on PubMed. The search was refined to results that were in the English language, conducted with human participants and took place in the United States. The following search terms were used for this purpose: (("Gestational weight gain" OR "GWG" AND ("pregnancy" AND "weight gain")) AND "trends") AND (full text[sb] AND Humans[Mesh] AND English[lang]). There were 23 articles produced from this search and 2 additional articles that were found in related articles that were relevant to the topic. The titles and abstracts of those publications were reviewed to see if they were related to the current research topic. Of the 25 articles reviewed, 11 were selected to be read in entirety for inclusion. Articles that were eligible for inclusion need to study the trends in GWG in the United States, whether trends in GWG was the original purpose of the study or not. Only 3 articles met the necessary criteria and were selected for use.

2.2 Findings

To our knowledge, only three studies (Chen et al., 2015; Harris et al., 2014; Johnson et al., 2015) have examined trends in GWG in the United States. The study by Harris and colleagues (2014) examined trends in GWG for women giving birth in Maine from 2000 to 2010 using Pregnancy Risk Assessment Monitoring System (PRAMS) data (n=12,571) (Harris et al., 2014). Researchers used linear regression techniques to look at trends for GWG, in addition to trends for smoking behaviors, pre-pregnancy BMI, alcohol consumption, C-section occurrences and infant outcomes. This study found a significant 0.24 lbs annual decrease in total GWG in contrast to a significant 0.15 units increase in maternal pre-pregnancy BMI per year over the 11-year period of study (Harris et al., 2014). The percentage of women who gained inadequate weight during pregnancy also significantly increased over time (0.4%/year) based on the 2009 IOM guidelines.

Chen et al. (2015) used data from Ohio birth certificates from 2006 to 2012 to examine trends in women meeting the 2009 IOM guidelines for GWG in a sample of 869,531 women who delivered singleton live births. The main goal of the study was to assess the population attributable risk for GWG on fetal growth outcomes, so the trend analysis for GWG was secondary. The study found that over 50% of participants had GWG that was considered above IOM guidelines in all pre-pregnancy BMI categories, with the highest proportion (70%) among overweight women (Chen et al., 2015). Authors did not find significant trend in excessive GWG over time, since the percentage of women that gained above IOM guidelines in each pre-pregnancy BMI category remained somewhat constant over the study period from 2006 until 2012.

Johnson et al. (2015) used PRAMS data, which included a sample of 124,348 pregnant women in 14 states from 2000 to 2009. Among the sample of singleton, full term live births, the study found a significant decrease in the proportion who gained within 1990 IOM guidelines and a significant increase in the proportion of women who gained above the recommendations over the period. Compared to 2000-2001, those who were pregnant during 2008-2009 were 10% less likely to meet 1990 IOM guidelines after adjusting for race/ethnicity, age, education, parity, hypertension status, diabetes status, Medicaid coverage, smoking behaviors and nausea during pregnancy in the analysis. They also found a statistically significant increase in GWG from 2000 to 2009 among overweight and class II obese women, while the proportion with inadequate GWG remained constant among all pre-pregnancy BMI categories.

2.3 Discussion

In brief, only Johnson et al. (2015) found a significant increasing trend in women gaining excessively over time and Harris et al. had an opposite finding, that GWG was decreasing over time and the percentage of women with inadequate GWG was increasing. The inconsistent findings might be caused by different methods used and different populations studied. As such, the current research on GWG trends has many limitations that need to be addressed. First, the studies used GWG as a categorical variable (using either the 1990 or the 2009 IOM recommendations). Johnson et al. (2015) used revised 1990 IOM recommendations, adding an upper limit (25 lbs) for GWG for overweight and obese women and using the lower limit of 15 pounds of weight gain. The studies by Harris (2014) and Chen (2015) used the 2009 IOM recommendations for categorizing GWG in their studies, which results in limited comparability between these studies. One critique with using these recommendations (as a categorical measure of GWG) in trend research is that they only include 3 categories to describe GWG, so the results may not fully illustrate the increasing trend for GWG over time. Grouping GWG in more descriptive ways, such as using percentiles, may portray how GWG is increasing at higher percentiles. For example, it is possible that the 90^{th} percentile of GWG z-scores is increasing. This would indicate that women that are among the heaviest 10 percent of the population are getting heavier.

Another limitation with the current research is that they all use linear analyses to show how GWG changes over time. This method is limited for research on GWG, since GWG data can be skewed with some women gaining excessive and some may lose weight during pregnancy. When excessive outliers are present, the mean or linear regression methods will not provide a good description of data patterns. After observing recent trends of increasing rates of obesity among women, we can assume that the GWG data will contain a large proportion of women gaining excessive weight. As stated before, African American women who are underweight or normal weight before pregnancy are more likely to gain inadequate weight during pregnancy. There may be a large proportion of women gaining inadequate weight in our dataset and that may cause it to be skewed. Using methods that are more robust to outliers and that track multiple categories of GWG (for example, 7 percentiles instead of 3 categories of IOM guidelines) will be better suited for this type of study. The use of quantile regression, instead of linear regression, may be helpful in this research as it allows us to use a model that requires less distributional assumptions and is more robust to the polarizing trends for GWG. Lastly, the research that is currently presented for GWG trends fails to account for important variables related to GWG. The studies by Chen (2015) and Harris (2014) did not adjust for variables such as gestational age, pre-pregnancy BMI, race or parity. These variables are highly related to GWG and failing to account for them yields an inaccurate portrayal of GWG trends. For example, GWG differs by gestational age since women gain more weight as the length of their pregnancy increases (Hutcheon et al., 2012). These studies assumed that GWG is comparable no matter how long the pregnancy lasted before delivery, which is an inaccurate assumption to make as weight gain would be variable according to week of gestation. Bias may be introduced in the study by failing to account for week of gestation, since women with preterm deliveries are more likely to be misclassified as experiencing inadequate GWG when it is not necessarily true (Hutcheon et al., 2012). Thus, current GWG trend research should focus on using analytic methods that display accurate distributional changes in GWG over time, choosing gestational-age standardized GWG measures, and adjusting for changes in confounding factors which could potentially impact the estimate of GWG trends.

Chapter 3

Methods

3.1 Study Population

The present study makes use of SC birth certificates from 2004 to 2015, which is a part of the National Vital Statistics system and mandates that information related to birth outcomes, maternal health and child health are collected at delivery. The full sample, before excluding women with missing values for key variables, was 668,667 women. This study includes only those women with singleton live births and without pre-existing conditions, such as diabetes, gestational diabetes, hypertension and gestational hypertension and having non-missing values for included variables such as gestational age at delivery, weight at delivery, pre-pregnancy weight, parity, body mass index, smoking behavior during pregnancy, race, age and urban rural residence, which resulted in a final sample of 525,411 women.

3.2 Exposure and Outcome of interest

The exposure of interest for this study is birth year, marked by years from 2004 until 2015. The study period began in 2004, which is the year that the revised birth certificates were used (National Vital Statistics System, 2017). The outcome of interest for Aim 1 and 2 is GWG, which is measured as GWGZ. Changes in GWGZ over the study period were calculated and regarded as showing a difference if the change was above .05 units, which was approximately half of a standard deviation difference in GWGZ from 2004 through 2005 until 2014 through 2015. Slight or modest differences were regarded as those less than .05 unit change. No improvement or decline was classified as a 0 unit change over the course of the study. These cut offs to label differences over time allowed for better interpretation of the trend results.

3.3 Potential Confounders

Below we described the variables used in the study.

I. *Race/ethnicity.* Race/ethnicity was ascertained through self-report and classifications include Non-Hispanic White, Non-Hispanic Black, Hispanic and Non-Hispanic others.

II. *Parity.* The number of previous pregnancies is related to GWG (Klingberg et al., 2017). This is obtained by collection of past medical records for each participant (Division of Vital Statistics National Center for Health Statistics, 2001). This parity measure excludes any pregnancies that do not result in a live birth according to medical records.

III. *Urban/rural residence.* County of residence will be used to classify women as residing in an urban/rural setting, according to county level urban/rural classifications ("Developing a rural definition," 2008).

IV. *Gestational Weight Gain.* Information about total weight gain during pregnancy in pounds was calculated as the difference between pre-pregnancy weight status and weight at delivery. GWG Z scores were used in this study, which use referent values (mean and standard deviations) from a cohort of women from Magee Women's Hospital in Pittsburgh, PA, used by Hutcheon and colleagues in research published in 2012 and 2015. We believe using z scores will provide a better measure of GWG since it standardizes the measure for GWG according to how many standard deviations it is to the reference GWG for the specific gestational age and pre-pregnancy BMI category. Understanding if there are large differences in GWGZ among some subgroups of the sample is informative since it demonstrates which groups are at higher risk for inappropriate GWG.

V. *Gestational age at delivery.* Gestational age at delivery in weeks is highly related to GWG. Gestational age at delivery is obtained through clinical estimates of gestational age.

VI. *Pre-pregnancy BMI category*. Measure calculated using pre-pregnancy BMI measure, categorized as underweight (BMI<18.5 kg/m^2), normal weight (BMI 18.5-24.9 kg/m^2), overweight (25-29.9 kg/m^2), obese class 1 (30-34.9 kg/m^2), obese class 2 (35-39.9 kg/m^2) and obese class 3 (BMI>40 kg/m^2).

VII. *Year at delivery.* The year of delivery includes the year recorded on the birth certificate in order to study trends of GWG over time. Years of study span from 2004 until 2015.

VIII. *WIC participation.* Self report measure of whether women were currently enrolled in the WIC food assistance program at the time of delivery.

IX. *Smoking behavior*. Self report measure of whether women smoked during pregnancy.

X. *Age.* The maternal age variables include the age recorded according to birth certificate records.

XI. *Birth cohort.* Birth cohort was determined according to women's own birth year and was categorized as being born before 1970, from 1970 to 1979, from 1980 to 1989 and after 1990. Only 209 women were born after 2000 (.04%), which were grouped into the last category. Women's birth year was estimated by subtracting the maternal age from the year of delivery, which was recorded on birth certificates.

3.4 Statistical Analysis

Existing studies focus mainly on mean values of total GWG using linear regression or GWG according to IOM recommendations using multinomial logistic regression. Neither of these approaches can capture the important shifts in GWG over time because they are confounded by the duration of gestational age. We use quantile regression, which is more useful in situations where extremes are important from a public health perspective. In this study, we are interested in trends in extremes. Quantile regression provides a more complete picture of the distributional change in GWG. Both excessive (upper quantile) and inadequate (lower quantile) GWG are closely watched because of their consequences on health outcomes. Compared with linear regression, quantile regression offers a better illustration of time trends for distributional changes in GWG. Further, it does not make a normal distribution assumption on the error terms, which is important due to the skewed nature of GWG values.

For the first study aim, we examined the 11-year trends in GWG. GWG, the outcome for our analysis, was measured as a continuous variable in pounds and converted to z scores (GWGZ). GWGZ, which accounts for pregnancy duration and pre-pregnancy BMI, depicts the number of standard deviations from the reference mean GWG value that each woman gains during pregnancy. GWGZ can be found by using a referent value for appropriate weight gain according to gestational age and the categories of pre-pregnancy BMI (underweight, normal weight, overweight, obese class 1, obese class 2 and obese class 3). The GWG referent values, which are smoothed and account for gestational age and pre-pregnancy weight status, are drawn from a cohort of women with healthy pregnancies from 1998 to 2010 in Pittsburgh, PA (Hutcheon et al., 2012, 2015). We make use of quantile regression of those GWGZ values to examine the association between time period (years between 2004 and 2015, independent variable) and GWG z-scores (dependent variable). We assessed trends for the 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles of GWGZ in order to observe the association between time period and the mean GWGZ for women who are considered in the highest percentile of GWG. This method is advantageous because we can look at the distribution of GWG at multiple points, as opposed to simply looking at mean GWG or categorizing it into the 3 categories according to IOM recommendations (inadequate, adequate and excessive). Another advantage to using this method is that it is not influenced by outliers or skewed data, which is important in studying GWG since the distribution for weight gain varies greatly. This means that this portion of the analysis requires no assumption about the distribution of the regression residuals. Mean values for the GWG z scores will be calculated for year and percentile to evaluate the trends over time. To control for confounding by changes in other characteristics over time, quantile regression also allows us to examine the trend in GWGZ across various percentiles while adjusting for covariates.

For the second study aim, we examined the differential trends of GWG in SC according to race/ethnicity, urban/rural residence and pre-pregnancy BMI and we also examined the trends after adjusting for potential confounders. Quantile regression is executed to control for the demographic variables in these models and to check the interaction between year and a few possible modifiers such as rural/urban residence, race and maternal pre-pregnancy BMI (underweight, normal weight, overweight, obese class 1, obese class 2 and obese class 3).

Chapter 4

Results

4.1 Population characteristics

Of the 525,411 women who had a singleton live birth delivered between 24 and 42 weeks of gestation in SC from 2004 to 2015, the majority were non-Hispanic White (55.9%), parous (58.9%), living in an urban setting (75.6%), participating in WIC (52.1%), and non-smokers during pregnancy (89.7%) (Table 4.1). Over 45% of them had normal weight before pregnancy, followed by 4.5% underweight, 25.3% overweight, 13.8% obese class 1, 6.6% obese class 2, and 4.6% obese class 3. Over half of these women were born in the 1980s (54%), followed by 26.3% born in the 1970s, and 16.9% born in the 1990s. Their mean age at delivery was 26.4 years with a standard deviation of 5.9 years (Table 4.1).

Table 4.1 also presents whether there was a significant linear trend in all characteristics over the years from 2004 to 2015. Overall, we saw a statistically significant trend over the years in most characteristics except normal weight, overweight, and obese class 1. Caution should be taken when interpreting very small but significant trends over time given the large sample size. Here we only highlight a few meaningful and consistent patterns of changes over the years. First, the percentages of non-Hispanic white women increased ($p= <.0001$), non-Hispanic Black women ($p=<.0001$) decreased and Hispanic women decreased (p value=<.0001) over the period. We also observed a steady increase in percentages being born to parous women, living in urban areas, and

Table 4.1 Sample characteristics of women who delivered a singleton live birth at 24-42 weeks of gestation in South Carolina from 2004 until 2015

Characteristics	Overall 2004- 2015	2004-2005	2006-2007	2008-2009	2010-2011	2012-2013	2014-2015	P value for trend[1]
Total N	**525,411**	**87,398**	**95,283**	**92,554**	**85,423**	**82,375**	**82,378**	
Race/ethnicity								
White	55.98	56.74	54.59	54.40	56.20	56.95	57.35	**<.0001**
Black	32.31	32.32	33.05	33.06	32.17	31.85	31.22	**<.0001**
Hispanic	9.48	8.82	10.26	10.36	9.30	8.80	9.14	**<.0001**
Other	2.23	2.12	2.09	2.17	2.33	2.39	2.30	**<.0001**
Parity								
Nulliparous	41.04	41.39	41.23	41.49	41.56	40.67	39.79	**<.0001**
Parous	58.96	58.61	58.77	58.51	58.44	59.33	60.21	**<.0001**
Residence								
Urban	75.59	74.08	74.47	75.46	76.04	76.64	77.10	**<.0001**
Rural	24.41	25.92	25.53	24.54	23.96	23.36	22.90	**<.0001**
WIC participation								
Yes	52.13	52.66	52.37	53.5	54.02	52.26	47.64	**<.0001**
No	46.27	45.63	46.05	45.02	44.45	45.96	50.81	**<.0001**
Pre-pregnancy BMI[2]								
Underweight	4.53	5.06	4.51	4.49	4.47	4.36	4.29	**<.0001**
Normal weight	45.11	46.39	44.45	44.16	44.69	45.85	45.27	0.5790
Overweight	25.29	25.08	25.58	25.76	25.23	24.82	25.19	0.0664
Obese class 1	13.81	13.11	14.24	14.15	13.94	13.68	13.68	0.3539
Obese class 2	6.63	6.26	6.72	6.68	6.82	6.56	6.76	**0.0030**
Obese class 3	4.62	4.10	4.50	4.76	4.86	4.73	4.81	**<.0001**
Smoking during pregnancy								
Smoker	10.29	13.24	11.51	10.41	9.54	8.59	7.99	**<.0001**
Non-smoker	89.71	86.76	88.49	89.59	90.46	91.41	92.01	**<.0001**
Birth cohort								
<1970	2.63	8.22	4.18	1.94	0.76	0.21	0.07	**<.0001**
1970-1979	26.32	44.14	36.38	28.5	21.73	14.98	9.42	**<.0001**
1980-1989	54.08	47.07	56.01	58.13	56.42	54.55	51.86	**<.0001**

≥1990	16.97	0.57	3.43	11.44	21.09	30.26	38.65	**<.0001**
Age (years)[3]								
Mean (SD)	26.36 (5.88)	25.95 (5.92)	26.04 (5.96)	26.37 (5.85)	26.02 (5.91)	26.72 (5.76)	27.16 (5.68)	**<.0001**
Gestational weight gain[3,4]								
Z score, mean (SD)	-0.40 (1.29)	-0.43 (1.36)	-0.51 (1.42)	-0.48 (1.35)	-0.41 (1.26)	-0.30 (1.13)	-0.26 (1.12)	**<.0001**

[1] P-values indicate whether the change in a specific characteristic was statistically significant over the years. They were based on Wald-test statistics for year variable when we treated the specific characteristic as a dichotomous outcome in unadjusted logistic regression model.

[2] Underweight: BMI<18.5 kg/m^2, Normal weight: BMI 18.5-24.9 kg/m^2, Overweight: 25-29.9 kg/m^2, Obese class 1: 30-34.9 kg/m^2, Obese class 2: 35-39.9 kg/m^2, Obese class 3: BMI>40 kg/m^2.

[3] P-values for continuous variables indicate statistically significant change in the characteristic over years of study, based off of an unadjusted linear regression model.

[4] Gestational weight gain z scores are calculated using smoothed reference values for maternal weight gain in pregnancy to account for gestational age and pre-pregnancy BMI (Hutcheon et al., 2012, 2015).

being in obese class 3. Second, over the period, the percentages of women participating in WIC and percentages of being smokers during pregnancy decreased. Finally, the mean age at delivery increased from 25.9 in 2004-2005 to 27.1 in 2014-2015 (Table 4.1).

4.2 Results

Women in the sample had an overall mean GWGZ of -.40 (SD=1.3), indicating that women in this SC population gained less weight on average than the reference sample (Table 4.1). Table 4.2 represents the unadjusted, mean GWGZ by year and according to sub groups of the population. From 2004 through 2005 until 2014 through 2015, we saw GWGZ changes from an average of -0.43 to -0.26, which indicates a significant trend (p= <.0001) (Table 4.2). According to the subgroups, those who gained the most weight during pregnancy were White (-0.25), nulliparous (-0.29), living in an urban residence (-0.38), not participating in the WIC program (-0.34), obese class 3 prior to pregnancy (-0.07), smokers during pregnancy (-0.38) and were born between 1970 and 1979 (-0.37) (Table 4.2). For all of the sub groups, there were significant differences in GWGZ between the levels of the variables (p=<.0001) (Table 4.2).

Table 4.3 presents the crude and adjusted GWGZ for percentiles (5^{th}, 10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 95^{th}) in our data over the years of study. In crude analysis, we observed that GWGZ increased by 0.76 units from 2004-2005 (-3.15) to 2014-2015 (-2.39) for the 5^{th} percentiles and this positive trend was attenuated as the percentiles went up. Increasing trends were seen for all percentiles aside from the 90^{th} and 95^{th}, where a slight decreasing trend was seen in the 90^{th} percentile (-.02 unit change) and a decreasing trend was seen for the 95^{th} percentile (-.07 unit change) (Table 4.3, Figure 4.1). After

Table 4.2. Mean GWG in sub groups South Carolina 2004-2015

GWGZ	Mean	Standard Deviation	P-value[1]
Overall	**-0.40**	**1.29**	**-**
Year			
2004-2005	-0.43	1.36	**<.0001**
2006-2007	-0.51	1.42	
2008-2009	-0.48	1.35	
2010-2011	-0.41	1.26	
2012-2013	-0.30	1.13	
2014-2015	-0.26	1.12	
Race/ethnicity			
White	-0.25	1.20	**<.0001**
Black	-0.57	1.39	
Hispanic	-0.68	1.26	
Other	-0.62	1.35	
Parity			
Nulliparous	-0.29	1.31	**<.0001**
Parous	-0.48	1.26	
Residence			
Urban	-0.38	1.27	**<.0001**
Rural	-0.48	1.33	
WIC participation			
Yes	-0.46	1.35	**<.0001**
No	-0.34	1.21	
Pre-pregnancy BMI[2]			
Underweight	-0.08	1.20	**<.0001**
Normal weight	-0.39	1.36	
Overweight	-0.56	1.31	
Obese class 1	-0.44	1.24	
Obese class 2	-0.23	1.01	
Obese class 3	-0.07	0.87	
Smoking during pregnancy			
Smoker	-0.38	1.38	**<.0001**
Non-smoker	-0.41	1.27	
Birth cohort			
<1970	-0.45	1.27	**<.0001**
1970-1979	-0.37	1.22	
1980-1989	-0.41	1.30	
≥1990	-0.43	1.34	

[1] P values were calculated using ANOVA for each categorical variable with no adjustment

[2] Underweight: BMI<18.5, Normal weight: BMI 18.5-24.9 kg/m^2, Overweight: 25-29.9 kg/m^2, Obese class 1: 30-34.9 kg/m^2, Obese class 2: 35-39.9 kg/m^2, Obese class 3: BMI>40 kg/m^2.

Table 4.3 Trends in gestational weight gain Z scores during 2004-2015 in overall sample and sub-samples stratified by race/ethnic group, South Carolina

GWG Z score Percentiles	5th	10th	25th	50th	75th	90th	95th
Crude							
2004-2005	-3.15	-2.42	-1.27	-0.35	0.36	1.01	1.41
2006-2007	-3.00	-2.29	-1.20	-0.33	0.37	1.01	1.39
2008-2009	-2.85	-2.15	-1.13	-0.30	0.38	1.00	1.38
2010-2011	-2.70	-2.01	-1.07	-0.28	0.39	1.00	1.37
2012-2013	-2.54	-1.87	-1.00	-0.25	0.40	0.99	1.35
2014-2015	-2.39	-1.73	-0.93	-0.23	0.41	0.99	1.34
Z score change since 2004	**.76**	**.69**	**.34**	**.12**	**.05**	**-.02**	**-.07**
Adjusted[1]							
2004-2005	-3.72	-2.73	-1.48	-0.41	0.40	1.08	1.51
2006-2007	-3.58	-2.64	-1.43	-0.39	0.40	1.08	1.50
2008-2009	-3.45	-2.54	-1.38	-0.38	0.41	1.08	1.49
2010-2011	-3.32	-2.44	-1.33	-0.36	0.41	1.07	1.48
2012-2013	-3.18	-2.34	-1.29	-0.34	0.41	1.07	1.48
2014-2015	-3.05	-2.24	-1.24	-0.33	0.41	1.06	1.47
Z score change since 2004	**.67**	**.49**	**.24**	**.08**	**.01**	**-.02**	**-.04**
White population[2]							
2004-2005	-3.24	-2.48	-1.21	-0.22	0.56	1.17	1.60
2006-2007	-3.13	-2.39	-1.17	-0.22	0.56	1.16	1.58
2008-2009	-3.01	-2.29	-1.14	-0.22	0.55	1.15	1.57
2010-2011	-2.90	-2.19	-1.10	-0.21	0.55	1.14	1.55
2012-2013	-2.79	-2.09	-1.06	-0.21	0.54	1.12	1.54
2014-2015	-2.67	-2.00	-1.02	-0.20	0.54	1.11	1.52
Z score change since 2004	**.57**	**.48**	**.19**	**.02**	**-.02**	**-.06**	**-.08**
African American population[2]							
2004-2005	-4.62	-3.10	-2.25	-0.97	-0.01	0.74	1.18
2006-2007	-4.57	-3.05	-2.19	-0.94	0.00	0.75	1.18
2008-2009	-4.51	-3.00	-2.13	-0.91	0.01	0.75	1.17
2010-2011	-4.45	-2.95	-2.07	-0.89	0.02	0.76	1.17
2012-2013	-4.40	-2.90	-2.01	-0.86	0.03	0.77	1.16
2014-2015	-4.34	-2.85	-1.95	-0.83	0.04	0.77	1.16
Z score change since 2004	**.28**	**.25**	**.30**	**.14**	**.05**	**.03**	**-.02**
Hispanic population[2]							
2004-2005	-3.82	-3.14	-1.88	-0.69	0.17	0.94	1.39
2006-2007	-3.69	-3.00	-1.80	-0.65	0.19	0.96	1.39
2008-2009	-3.55	-2.87	-1.71	-0.61	0.22	0.98	1.40
2010-2011	-3.41	-2.73	-1.63	-0.57	0.25	0.99	1.40
2012-2013	-3.27	-2.59	-1.54	-0.53	0.28	1.01	1.41
2014-2015	-3.13	-2.46	-1.46	-0.49	0.30	1.03	1.41
Z score change since 2004	**.69**	**.68**	**.42**	**.20**	**.13**	**.09**	**.02**

[1] Adjustment for race/ethnicity, parity, urban/rural residence, WIC participation, pre-pregnancy BMI, smoking behavior, age and birth cohort.

[2] Based on a model adjusting for parity, urban/rural residence, WIC participation, pre-pregnancy BMI, smoking behavior, age and birth cohort.

Key for Figures 4.1 and 4.2

■ - · - ■	**95th percentile**	● —— ●	**50th percentile**	● - · - ●	**5th percentile**
× ····· ×	**90th percentile**	◆ - · - ◆	**25th percentile**		
● - - - ●	**75th percentile**	▲ — — ▲	**10th percentile**		

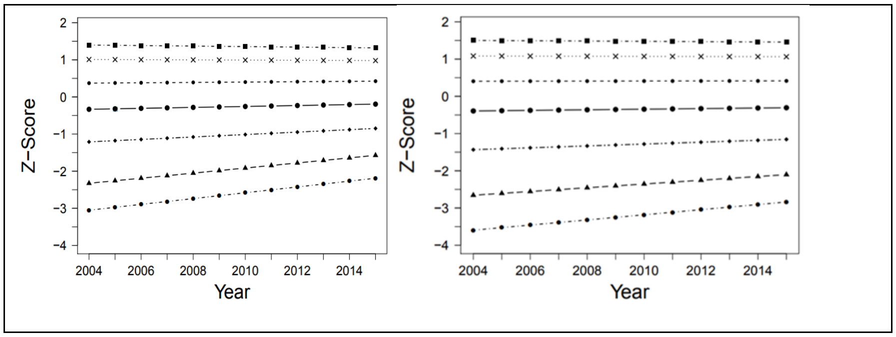

Figure 4.1 Crude (left) and adjusted* (right) trends in GWG z scores by GWG Z percentile, South Carolina 2004-2015

* adjusted for pre-pregnancy BMI, race/ethnicity, parity, WIC participation, smoking behavior, residence, age and birth cohort.

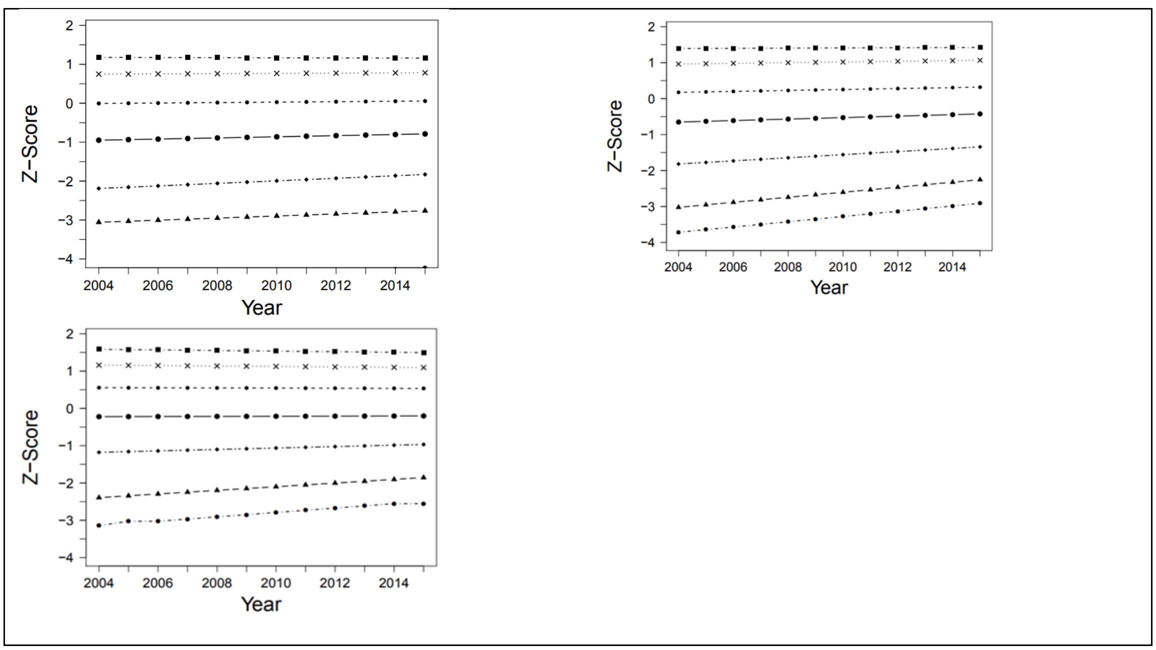

Figure 4.2 Adjusted* trends for White, black, Hispanic women in GWG z scores by percentile, South Carolina 2004-2015

* adjusted for pre-pregnancy BMI, race/ethnicity, parity, WIC participation, smoking behavior, residence, age and birth cohort.

adjusting for parity, urban/rural residence, WIC participation, pre-pregnancy BMI, smoking behavior, age and birth cohort, the trends were somewhat persistent (Table 4.3). We observed that GWGZ increased by 1.00 units from 2004-2005 (-3.64) to 2014-2015 (-2.64) for the 5th percentile. In the 90th percentile, there was no difference in the change in GWGZ over the study period (-0.02) between the crude and adjusted analysis but the adjusted model showed slightly higher values for GWG compared to the reference population (changing from 1.64 in 2004 through 2005 to 1.57 in 2014 through 2015) (Table 4.3). In the highest percentile observed, the decreasing trend was attenuated so that there was only a slight decreasing trend for the adjusted model (decreasing by .04 units over the study period). Figure 4.1 displays the adjusted trends in GWGZ over the study period, which also shows noticeable increases in GWGZ in the lower percentiles and small or minor decreases in GWGZ in the higher percentiles.

Trends also varied by race/ethnic sub-groups. At the 5th percentile, the White population showed 0.57 unit increase in GWGZ (from -3.24 from 2004 through 2005 to -2.67 from 2014 through 2015), the African American population showed a 0.28 increase in GWGZ (from -4.62 from 2004 through 2005 to -4.34 from 2014 through 2015) and the Hispanic population showed a 0.69 increase in GWGZ (from -3.82 from 2004 through 2005 to -3.13 from 2014 through 2015) (Table 4.3). The African American population showed the lowest increase over the study period in this sample. In the 50th percentile, the White population showed a slight increase (0.02 units) in GWGZ from 2004-2005 to from 2014-2015, while the African American and Hispanic women showed a higher increase in GWGZ (Table 4.3). African American and Hispanic populations show the largest increases in GWGZ from 2004 until 2015. In the 95th percentile, the White population showed a 0.08 decrease in GWGZ (from 1.60 in 2004 through 2005 to 1.52 from 2014 through 2015), the African American population showed a 0.02 decrease in GWGZ (from 1.18 in 2004 through 2005 to 1.16 from 2014 through 2015) and the Hispanic population showed a 0.02 increase in GWGZ over the same time period (from 1.39 in 2004 through 2005 to 1.41 from 2014 through 2015) (Table 4.3). The changes for minority populations was modest compared to the changes for the White population in the 95th percentile. Figure 4.2 accurately display the trends in GWGZ from 2004 through 2015 for White, Black and Hispanic women, respectively. We observe an increasing trend in GWGZ for White women in the 5th percentile and decreasing trends in the highest percentiles (90th and 95th). For Black women, we observe the lowest GWGZ in the lower percentile with an increasing trend and only slightly decreasing trends in the highest percentile. For this population, there was a notable but modest increasing trend for the 90th percentile of GWGZ. For Hispanic women, we observe an increasing trend in the lowest percentiles and a slight increasing trend in the 95th percentile.

Table 4.4 displays the adjusted GWGZ for percentiles (5th, 10th, 25th, 50th, 75th, 90th, and 95th) in our data over the years of study stratifying by urban/rural residence and pre-pregnancy BMI category. In the 5th percentile, women who lived in an urban residence showed a 0.53 unit increase in GWG (from -3.48 in 2004 through 2005 to -2.95 in 2014 through 2015), while women who lived in a rural residence showed a 0.49 unit increase in GWG for the period (Table 4.4). In the 50th percentile, rural residents had a higher increase in GWGZ, increasing by .11 units (from -.38 in 2004 through 2005 to -.27 in 2014 through 2015), while urban residents had a slight increase of only .03 units (from -.32 in 2004 through 2005 to -.29 in 2014 through 2015) (Table 4.4). Starting from

Table 4.4 Trends in gestational weight gain Z scores during 2004-2015, stratified by urban/rural residence and pre-pregnancy BMI, South Carolina 2004-2015

GWG Z score Percentiles	5th	10th	25th	50th	75th	90th	95th
Urban residence[1]							
2004-2005	-3.48	-2.58	-1.36	-0.32	0.51	1.19	1.62
2006-2007	-3.62	-2.70	-1.48	-0.39	0.47	1.17	1.61
2008-2009	-3.51	-2.61	-1.43	-0.39	0.44	1.13	1.56
2010-2011	-3.33	-2.46	-1.34	-0.36	0.45	1.12	1.53
2012-2013	-2.97	-2.22	-1.24	-0.31	0.48	1.14	1.55
2014-2015	-2.95	-2.20	-1.22	-0.29	0.50	1.16	1.58
Z score change since 2004	**0.53**	**0.38**	**0.14**	**0.03**	**-0.01**	**-0.03**	**-0.04**
Rural residence[1]							
2004-2005	-3.60	-2.55	-1.39	-0.38	0.42	1.14	1.58
2006-2007	-3.62	-2.61	-1.47	-0.45	0.37	1.12	1.56
2008-2009	-3.60	-2.57	-1.44	-0.45	0.35	1.08	1.51
2010-2011	-3.46	-2.46	-1.36	-0.42	0.35	1.07	1.48
2012-2013	-3.17	-2.21	-1.20	-0.32	0.42	1.14	1.54
2014-2015	-3.11	-2.17	-1.15	-0.27	0.47	1.17	1.58
Z score change since 2004	**0.49**	**0.38**	**0.24**	**0.11**	**0.05**	**0.03**	**0.00**
Underweight before pregnancy [2]							
2004-2005	-1.91	-1.41	-0.62	0.09	0.76	1.34	1.79
2006-2007	-2.02	-1.47	-0.64	0.05	0.72	1.34	1.80
2008-2009	-2.03	-1.54	-0.71	0.01	0.69	1.30	1.77
2010-2011	-2.00	-1.55	-0.74	0.01	0.64	1.26	1.74
2012-2013	-2.03	-1.55	-0.75	-0.04	0.61	1.18	1.61
2014-2015	-1.96	-1.46	-0.68	0.01	0.67	1.24	1.70
Z score change since 2004	**-0.05**	**-0.05**	**-0.06**	**-0.08**	**-0.09**	**-0.10**	**-0.09**
Normal weight before pregnancy [2]							
2004-2005	-3.76	-2.33	-1.14	-0.24	0.57	1.27	1.71
2006-2007	-4.00	-2.47	-1.20	-0.29	0.54	1.25	1.69
2008-2009	-3.84	-2.41	-1.23	-0.33	0.49	1.18	1.60
2010-2011	-3.52	-2.29	-1.21	-0.33	0.48	1.17	1.57
2012-2013	-3.19	-2.19	-1.19	-0.32	0.48	1.18	1.58
2014-2015	-3.19	-2.18	-1.16	-0.29	0.50	1.21	1.64
Z score change since 2004	**0.57**	**0.15**	**-0.02**	**-0.05**	**-0.07**	**-0.06**	**-0.07**
Overweight before pregnancy [2]							
2004-2005	-3.23	-3.23	-1.73	-0.42	0.36	0.96	1.35
2006-2007	-3.26	-3.30	-1.92	-0.50	0.34	0.97	1.35
2008-2009	-3.24	-3.23	-1.73	-0.47	0.33	0.95	1.34
2010-2011	-3.15	-3.01	-1.57	-0.41	0.34	0.95	1.31
2012-2013	-2.69	-2.33	-1.38	-0.32	0.39	0.97	1.35
2014-2015	-2.55	-2.23	-1.36	-0.31	0.41	0.98	1.36
Z score change since 2004	**0.68**	**1.00**	**0.37**	**0.11**	**0.05**	**0.02**	**0.01**
Obese class 1 before pregnancy[2]							
2004-2005	-2.15	-2.11	-1.81	-0.40	0.41	1.03	1.29
2006-2007	-2.19	-2.13	-2.03	-0.50	0.34	0.96	1.23
2008-2009	-2.17	-2.12	-1.84	-0.44	0.34	0.95	1.23

2010-2011	-2.14	-2.08	-1.50	-0.37	0.36	0.95	1.20
2012-2013	-1.96	-1.74	-1.27	-0.24	0.46	1.01	1.25
2014-2015	-1.94	-1.61	-1.22	-0.20	0.50	1.06	1.28
Z score change since 2004	**0.21**	**0.50**	**0.59**	**0.20**	**0.09**	**0.03**	**-0.01**
Obese class 2 before pregnancy[2]							
2004-2005	-1.52	-1.37	-1.29	-0.29	0.45	0.99	1.37
2006-2007	-1.56	-1.40	-1.37	-0.39	0.35	0.91	1.32
2008-2009	-1.55	-1.37	-1.31	-0.35	0.37	0.92	1.31
2010-2011	-1.54	-1.36	-1.22	-0.27	0.40	0.93	1.29
2012-2013	-1.47	-1.25	-0.89	-0.14	0.49	1.05	1.42
2014-2015	-1.48	-1.23	-0.88	-0.14	0.48	1.00	1.36
Z score change since 2004	**0.04**	**0.14**	**0.41**	**0.15**	**0.03**	**0.01**	**-0.01**
Obese class 3 before pregnancy [2]							
2004-2005	-1.09	-0.75	-0.72	-0.07	0.46	0.90	1.11
2006-2007	-1.17	-0.77	-0.77	-0.18	0.41	0.85	1.07
2008-2009	-1.09	-0.75	-0.73	-0.12	0.43	0.83	1.07
2010-2011	-1.24	-0.77	-0.70	-0.07	0.44	0.84	1.06
2012-2013	-1.35	-0.77	-0.53	0.03	0.51	0.89	1.08
2014-2015	-1.43	-0.85	-0.54	0.01	0.52	0.89	1.11
Z score change since 2004	**-0.34**	**-0.10**	**0.18**	**0.08**	**0.06**	**-0.01**	**0.00**

[1] Based on a model adjusting for parity, race/ethnicity, WIC participation, pre-pregnancy BMI, smoking behavior, age and birth cohort.

[2] Based on a model adjusting for parity, race/ethnicity, WIC participation, urban/rural residence, smoking behavior, age and birth cohort.

75^{th} percentile, urban residents had modest decreases in GWGZ (ranging from -0.01 to -0.04) while rural residents still showed the small positive increase in GWGZ ranging from .05 at the 75^{th} percentile to no change at the 95^{th} percentile (Table 4.4). Important differences in GWGZ were also seen when data was stratified by pre-pregnancy BMI category. For women who were underweight before they became pregnant, we saw a consistent decrease in GWGZ for all percentiles ranging from -0.05 to -0.10 over the study period and this SC population also shows lower GWGZ than the reference population in the lower percentiles (5^{th}, 10^{th} and 25^{th}) (Table 4.4). For women who are normal weight before pregnancy, we saw a positive increase at the 5^{th} (0.57 unit) and 10^{th} (0.15 unit) percentiles. Starting from 25^{th} percentiles to the highest percentiles, GWGZ experienced a decreasing trend over time ranging from -0.06 to -0.10 over the period (Table 4.4). For women who were overweight or obese classes 1 and 2 prior to pregnancy, they experienced an increase in GWGZ at all percentiles over the period although the magnitude varied between them. For overweight women, the increase in GWGZ was higher at the 5^{th} percentile (0.68 increase) and reduced as percentiles increased (a .01 unit increase in the 95^{th} percentile). For women who were considered obese class 1 or class 2 prior to pregnancy, the increase was highest among the 25^{th} percentile with a larger magnitude of increase shown in obese class 1 women. For women who were considered obese class 3 prior to pregnancy, there was a decrease in GWGZ at the lowest percentile (-0.34 at 5^{th} percentile and -0.10 at 10^{th} percentile) but we saw an increase in GWGZ for other percentiles (25^{th}, 50^{th}, and 75^{th} percentile) (Table 4.4). It is apparent that there was minimal change in GWGZ in the highest percentiles in overweight and obese women and GWGZ trends varied by pre-pregnancy weight in low or mid-percentiles.

Table 4.5 displays the adjusted quantile regression estimates for the associations of key variables with GWGZ on the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles of GWGZ. For birth year, compared to 2014-2015, other years had significantly lower GWGZ at 5th percentile at 10th percentile. For the higher percentiles, the earlier years showed a higher GWGZ. This confirms the increasing trend in GWGZ at the lower percentiles and decreasing trend at the higher percentiles (Table 4.5).

For race/ethnicity, Blacks, Hispanics, non-Hispanic others had significantly lower GWGZ in the 50th percentile or lower, and they had significantly higher GWGZ in the 75th percentiles or higher (Table 4.5). Similarly, parous, rural, non-WIC participants, underweight, overweight/obese women, smokers, and being born before 1990 had significantly lower GWGZ scores than at the lower percentiles (25th or 50th percentiles or lower) compared to their counterparts. Nulliparous, urban, WIC participants, underweight, smoking women had higher GWGZ scores than their counterparts at the higher percentiles. Lastly, for every one year increase in maternal age, there was a significant decrease in GWGZ in the 50th percentile or lower but and a significant increase in GWGZ in the higher percentiles (≥ 75th percentile) (Table 4.5).

Table 4.5. Estimated parameters by percentiles for gestational weight gain Z scores by key variable, South Carolina 2004-2015

	GWG Z score[1]						
Percentiles	**5th**	**10th**	**25th**	**50th**	**75th**	**90th**	**95th**
Intercept	-2.96	-2.18	-1.19	-0.27	0.51	1.17	1.59
Year							
2004-2005	-3.49***	-2.56***	-1.35***	-0.32***	0.51	1.19	1.62*
2006-2007	-3.60***	-2.67***	-1.47***	-0.38***	0.47***	1.17	1.60
2008-2009	-3.51***	-2.59***	-1.41***	-0.39***	0.44***	1.13***	1.56**
2010-2011	-3.33***	-2.45***	-1.33***	-0.35***	0.44***	1.13***	1.53***
2012-2013	-2.99***	-2.21*	-1.22***	-0.29***	0.48***	1.15**	1.56**
2014-2015	REF	REF	REF	REF	REF	REF	REF
Race/ethnicity							
White	REF	REF	REF	REF	REF	REF	REF
Black	-3.37***	-2.52***	-1.55***	-0.51***	0.35***	1.08***	1.52***
Hispanic	-3.20***	-2.48***	-1.58***	-0.64***	0.16***	0.85***	1.28***
Others	-3.42***	-2.63***	-1.62***	-0.59***	0.20***	0.88***	1.30***
Parity							
Nulliparous	REF	REF	REF	REF	REF	REF	REF
Parous	-3.11***	-2.34***	-1.42***	-0.51***	0.28***	0.96***	1.38***
Residence							
Urban	REF	REF	REF	REF	REF	REF	REF
Rural	-3.02***	-2.23***	-1.26***	-0.34***	0.45***	1.13***	1.56**
WIC							
Yes	REF	REF	REF	REF	REF	REF	REF
No	-2.89***	-2.12***	-1.17***	-0.29***	0.45***	1.08***	1.48***
Pre-pregnancy BMI							
Underweight	-2.11***	-1.68***	-0.86***	-0.04***	0.70***	1.35***	1.75***
Normal weight	REF	REF	REF	REF	REF	REF	REF
Overweight	-2.88***	-2.61***	-1.33***	-0.34***	0.40***	1.00***	1.37***
Obese 1	-2.25***	-2.06***	-1.27***	-0.25***	0.48***	1.08***	1.43***

Obese 2	-1.71***	-1.48***	-0.93***	-0.10***	0.54***	1.05***	1.37***
Obese 3	-1.44***	-1.09***	-0.54***	0.06***	0.58***	0.99***	1.25***
Smoking behavior							
Yes	-3.09***	-2.32***	-1.28***	-0.27	0.59***	1.31***	1.74***
No	REF	REF	REF	REF	REF	REF	REF
Birth cohort							
<1970	-3.13***	-2.41***	-1.40***	-0.42***	0.37***	1.08***	1.53
1970-1979	-2.93	-2.19	-1.21	-0.28**	0.48*	1.15	1.59
1980-1989	-2.86***	-2.11***	-1.16**	-0.25	0.51	1.18	1.60
>=1990	REF	REF	REF	REF	REF	REF	REF
Age (per one year increase)							
	-2.93***	-2.15***	-1.17***	-0.26***	0.51***	1.18***	1.59*

*** = p<0.001, ** = p <0.01, * = 0.01 <p<0.05

All estimates are based off of a quantile regression model with adjustment for race/ethnicity, parity, urban/rural residence, WIC participation, pre-pregnancy BMI, smoking behavior, age and birth cohort.

[1] Gestational weight gain z scores are calculated using smoothed reference values for maternal weight gain in pregnancy to account for gestational age and pre-pregnancy BMI (Hutcheon et al., 2012, 2015).

Chapter 5
Conclusions

5.1 Discussion

In this SC sample, we saw an overall increase in GWGZ in the 5th, 10th, 25th, 50th, 75th percentiles and an overall decrease in GWGZ in the 90th, and 95th percentiles. Compared to the reference sample, GWGZ was lower in the 5th, 10th, 25th and 50th percentiles and higher in the 75th, 90th and 95th percentiles for the entire study period (2004 until 2015) after adjustment for parity, urban/rural residence, WIC participation, pre-pregnancy BMI, smoking behavior, age and birth cohort. In the 5th percentile, the White population had much larger increases in GWGZ compared to the African American population, despite the fact that African Americans had significantly lower GWGZ overall. In the 95th percentile, the White population had a greater decrease in GWGZ compared to the African American population, despite the fact that the GWGZ in this percentile for White and Black women was not significantly different. For the Hispanic population in the 95th percentile, there was an increasing trend in GWGZ from 2004 through 2005 to 2014 through 2015 and Hispanic women have significantly higher GWGZ in this percentile compared to White women. These results offer some empirical evidence on the possible increasing trends in Hispanic women at high GWGZ percentile and white women showed more promising trends in GWG over time than African Americans. This underscores the fact that maternal health risks have increased in minority populations over time and merit more concerted public health efforts.

over the study period compared to urban women. This suggests that the health needs of pregnant women in an urban setting in this population may be better met than that for pregnant women in a rural setting. For urban/rural residence, the mean GWGZ was consistently lower among rural residents compared to urban residents for all percentiles. Rural residents experienced similar increases in GWGZ in the 5th percentile and no change in GWGZ in the 95th percentile. This finding somewhat contradicts the findings of past research, which say that rural residence is protective against excessive GWG (Gallagher et al., 2013).

When observing changes in GWGZ according to pre-pregnancy BMI, underweight and obese class 3 showed a decrease and normal weight, overweight, obese class 1 and obese class 2 showed an increase in GWGZ over time in the 5th percentile. Also, underweight, overweight and obese women had significantly lower GWGZ compared to normal weight women in this percentile. In the 95th percentile, underweight, normal weight, obese class 1 and obese class 2 had a slight decreasing trend in GWGZ, overweight had slight increasing trends in GWGZ and obese class 3 shows no change. Underweight, overweight and obese women showed significantly higher GWGZ compared to normal weight women in the highest percentile. While improvements in GWG occurred for these pre-pregnancy BMI categories over the study period, more drastic decreases in the higher percentiles in overweight and obese women is necessary to positively impact health. Another important trend to note is that underweight women gained less weight over time in every percentile. This is concerning, since GWG should be increasing in lower percentiles where inadequate GWG is a health risk.

5.2 Trend Comparisons

Our results were comparable to those reported by Harris et al. (2014) paper looking at GWG trends. Harris et al. (2014) found a significant annual decrease in total GWG in contrast to a significant increase in maternal pre-pregnancy BMI per year over the 11-year period of study. The present study also found a decrease in GWG when examining GWGZ means from 2004 to 2015, under the backdrop of significant increases in the prevalence of women who are considered obese class 2 and 3 before pregnancy. In the Harris et al. study (2014), the percentage of women who gained inadequate weight during pregnancy also significantly increased over time (0.4%/year) based on the 2009 IOM guidelines. The current research did not study IOM recommendations but, while adjusting for parity, urban/rural residence, WIC participation, pre-pregnancy BMI, smoking behavior, age and birth cohort, this study saw an increase in GWGZ in the lower percentiles of weight gain. In addition, this study highlights the fact that African American population in SC is gaining significantly less weight in the lower percentiles of weight gain and is showing less improvement in GWG over time. When stratified by race, African American women showed a modest increase in the 5th percentile over the study period, but the increase was less than that for White women. Overall, African American women also had much lower GWGZ compared to White women in the lower percentiles of GWGZ. The study by Chen et al. (2015) found that over half of participants had GWG that was considered above IOM guidelines in all pre-pregnancy BMI categories, with the highest proportion among overweight women (Chen et al., 2015). Despite this fact, the study did not observe a significant trend in excessive GWG over the study period (2006 until 2012) (Chen et al., 2015). The current research used quantile regression, which allowed us to find that GWGZ in the higher percentiles of weight gain, such as the 90th and the 95th, was decreasing over time. Our study also found that women who were considered overweight and obese prior to pregnancy gained more weight than normal weight women in the higher percentiles for GWGZ (75th, 90th and 95th). This suggests there is increased risk for higher GWGZ for women who are overweight or obese prior to pregnancy compared to normal weight participants. Johnson et al. (2015) in their study of a sample of singleton, full term live births in 14 states found a significant decrease in the proportion who gained within 1990 IOM guidelines and a significant increase in the proportion of women who gained above the recommendations over the period. The current study did not look at GWG in relation to IOM recommendations. Yet our findings of small decreasing trend in GWGZ at higher percentiles of GWGZ in comparison to a reference population are somewhat consistent with Johnson et al. findings. In addition, similar to the findings of increased mean GWG over time in Johnson et al (2015), we also found GWGZ scores increased over time (from -.43 in 2004 through 2005 to -.26 in 2014 through 2015).

Past studies that examined trends in GWG used different GWG measures and regression techniques. It is clear that the current study is advantageous by illustrating the different trends by GWGZ percentiles. One major advantage of using GWGZ is that it accounts for gestational age. Women who have shorter pregnancies tend to gain less weight during pregnancy, so it is important to account for gestational age. Furthermore, our method also accounts for pre-pregnancy BMI in the GWGZ calculation, adjusts for changing in key variables over time and displays distributional change in the sample over time using quantile regression. Our results are consistent with past studies that used mean

GWG to study trends reported an increasing trend in GWG since we saw similar results in this sample when looking at mean GWGZ. Our study advances the literature by also looking at z scores that better represent GWG, so distributional shifts in higher and lower percentiles can also be examined. Future research that examines GWG trends should use similar methods to understand population changes in GWG over time.

5.3 Strengths and Limitations

The current study contributes to research on GWG trends by including a large sample size, a long study period and innovative statistical analyses. In response to recent increases in obesity rates in the United States, it is important to conduct trend analyses in GWG in order to inform future research, policy and interventions. The current study includes accurate measures for GWG and uses better regression methods to depict trends in GWG.

The advanced methods of the current research results in much more detailed GWG trends, yet some similarities remain between this study and past trend analyses. GWGZ are used as the measure for GWG, which represents the deviation from appropriate GWG (represented by a reference sample provided by Hutcheon et al., 2012, 2015). These z scores are useful because they allow us to observe changes in GWG over time while accounting for gestational age and the pre-pregnancy BMI category of the mother. The majority of past GWG trend research fails to do so, meaning that GWG estimates fail to account for two significant predictors for pregnancy weight gain. Looking at trends for mean GWG using linear regression may also be biased, since the data on GWG may be skewed and therefor it will impact the results. Trends based on whether IOM guidelines for GWG were met or not is also inappropriate, since these three categories (including inadequate, adequate and excessive GWG) may not depict important changes in GWG that would be seen if the measure was segregated into more categories (such as percentiles of GWG). Past research looking at GWG trends did not show consistent results: Harris et al. (2014) found that the fraction of those gaining within recommendations remained the same over the study period, Chen et al. (2015) saw no significant trends and Johnson et al. (2015) saw a significant decrease of those gaining within and an increase in those gaining above IOM guidelines. It is clear that more precise methods for looking at trends, which include seven percentiles to track distributional shifts over time and GWG measures that account for gestational age, will yield more consistent findings in future trend analyses. In addition, accounting for changes in population characteristics in our analysis allows us to control for differences over time that may be driving the trends that are observed in research using less complex methods. Since there are such important differences according to key demographic variables with regard to GWG, it is crucial to account for and observe these changes by accounting for them in the GWG z-score measure, controlling for them in the analysis and stratifying by important effect modifiers.

Past research that looked at changes in mean GWG over time, as oppsed to whether women met IOM guidelines, predominantly used linear regression techniques to analyze changes over time. This is problematic since an important assumption for this method is that data are not highly skewed and that is not accounted for when using the mean GWG measure. High proportions of excessive and inadequate weight gain during pregnancy may bias the risk estimates. For this reason, quantile regression methods in the current research allow for a robust and informative statistical analysis. Studying the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles is useful since it may capture not only the monotonic increasing or decreasing trends over time as well as the divergent trends at different percentiles, which cannot be captured by using mean GWG. In addition, the study's use of quantile regression highlights the persistent issue of SC women gaining more weight during pregnancy in higher percentiles and gaining less weight in lower percentiles compared to the reference group to demonstrate important health disparities in SC. It is more informative to observe how each percentile of weight gain is changing over time, especially when stratifying by race, to see what health issues specifically need to be addressed. This study meticulously examines differences according to variables such as race/ethnicity, urban/rural residence and pre-pregnancy BMI to understand how these groups show different trends compared the overall trend using these superior methods for analysis.

The current research has many strengths, but one of the major limitations is the crude estimate urban or rural classification. Rural and urban residence was based off of county level classifications since we did not have access to the home addresses of each participant. Although each county is not homogeneous with regard to urban or rural environment, these classifications were sufficient due their availability in the vital statistics dataset. Another limitation is that this study used z scores for GWG that were adapted from previous studies by Hutcheon et al. (2012, 2015). This author used a sample of women from Pittsburgh, Pennsylvania as a reference group that is comparable to the national population. This method is advantageous because it accounts for key variables, such as gestational age and pre-pregnancy BMI, which show important changes over time that may impact the results. A drawback from this method is that the reference sample may not be representative of all pregnancies in the United States and may be an inappropriate comparison group to SC. The differences between the reference population and the study population should be acknowledged during interpretation of results. It should be noted that the z scores compare GWG between South Carolina and Pennsylvania populations at each week of gestation and may not truly represent differences between South Carolina and the entire United States.

5.4 Implications

Our study includes a large, representative sample of women from SC and uses more advanced methodology to analyze the GWG data. Future research studying trends related to GWG should make use of these methods to more accurately depict change over time. Due to the fact that gestational age impacts the results of research in GWG, use of z scores is necessary in order to avoid the confounding effects of this variable. In addition, due to the fact that compliance with IOM recommendations is not improving over time and the categories indicating adequacy are so broad, use of quantile regression to understand the distributional shifts of GWG over time is much more informative. Our results depict clear changes in GWG that can be used to produce more consistent and conclusive results in the future. In addition, being able to specifically examine high ris groups and how they are changing with regard to GWG over time is crucial. This research should inform policy towards providing better care for pregnant women in this state, especially for racial minority groups. These groups contribute greatly to the inadequate and excessive GWG trends observed in past research and future research should make it a priority to observe the underlying factors for the changes seen in GWG over time.

5.5 Conclusion

Our study characterized GWG over the past decade and examined whether important trends are occurring in SC. Nationally there have been increases in obesity in reproductive aged women so determining how GWG is changing in SC is important for informing areas for improvement in the field of maternal and child health. We found that in SC, there have been modest increases in GWGZ in the lowest percentiles and modest decreases in GWGZ in the highest percentiles in the period fo 2004-2015. After adjustment for parity, urban/rural residence, WIC participation, pre-pregnancy BMI, smoking behavior, age and birth cohort, the increasing trend was slightly smaller overall and the decreasing trend in the higher percentiles remained somewhat the same. Using quantile regression, GWG z scores and adjusting for key variables are methodological advances in for studying these trends. Further, subgroup analyses by race/ethnicity, urban/rural residence and pre-pregnancy BMI show which high risk groups are not showing marked improvements in GWG. Although these trends are moving in a positive direction overall, more must be done to address the issue of inappropriate GWG in certain high risk groups.

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